Report: LDO - 201608

Title: Search for the flight MH370 impact site in the Indian Ocean from hydroacoustic data March 8, 2014

Author: Jean-Yves Royer

Issued: 22 December 2016

Contact
jean-yves.royer@univ-brest.fr
Laboratoire Domaines Océaniques – CNRS/UBO
Institut Universitaire Européen de la Mer
29280 Plouzané, France
Tel.: +33 298 49 87 40
https://www-iuem.univ-brest.fr/ldo/fr

Search for the flight MH370 impact site in the Indian Ocean from hydroacoustic data, March 8, 2014

Introduction

At the time of the disappearance of Malaysian Airlines flight MH370, a network of autonomous hydrophones, named OHASISBIO, was active in the southern Indian Ocean (Figure 1). The purpose of this network is to continuously monitor the low-frequency sounds (0-120 Hz) generated in the ocean by submarine earthquakes and volcanic eruptions on the seafloor, vocalizations of large baleen whales, icequakes and ice-tremors, and the low-frequency ambient noise in general.

In 2014, the network comprised 6 sites (Fig. 1; location in Table 1) with one autonomous hydrophone per site, except for the SWAMS site equipped with 3 hydrophones, positioned 10 km apart and forming an equilateral triangle. The hydrophones were deployed in January-February 2014 and recovered in January-February 2015 during the yearly voyages of RV *Marion Dufresne* to the French Southern Territories in the Indian Ocean (Crozet, Kerguelen and Amsterdam islands, Fig. 1).

At the time of the disappearance of flight MH370 and search for the airplane flight recorders (i.e. "black boxes"), the existence of this hydrophone network was brought to the attention of the French *Bureau d'Enquêtes et d'Analyses* (BEA). However the low sampling rate (240 Hz) of the hydrophones was inappropriate to detect the 37.5 kHz broadcast from the flight recorders.

In this report, we examine the acoustic data collected by the OHASISBIO hydrophones, in conjunction with the data recorded by the IMS-CTBTO permanent hydroacoustic stations off Cape Leeuwin, Australia (station H01W), and off Diego Garcia Island (station H08S). Some events of unknown origin can tentatively be located in the vicinity of the presumed impact area. However it must be stressed that the association of events recorded by the hydrophones is non-unique, and furthermore, the picked events are very faint and often hardly distinguishable from the background acoustic noise. **The inferred location of the source of these events must then be considered with extreme caution. Furthermore, even if correct, we cannot tell whether these acoustic events are related to the disappearance of flight MH370.**

Data information

All OHASISBIO instruments, but one, were recovered and recorded data March 8, 2014. Unfortunately, the hydrophone closest to the presumed impact area (NEAMS) was lost during recovery. In addition, that day, most of the data are obscured by powerful seismic shots from an exploration survey.

The data are sampled continuously at 240Hz and stored in 3 bytes word (24 bits A/D converter). The raw data are in counts (2^24 counts for 5 V); the Volt to Pascal conversion depends on the sensitivity of the HTI sensors (see Table 3 in the Appendix). Each data file comprises an ASCII header of 400 bytes followed by a series of samples in big-endian binary format (Persistor processor). The header details the data format, sampling rate, GPS synchronization time, number of samples in the file, time and ordinal number of the file 1st sample, etc. More information on the instruments can be found in D'Eu et al. (2012).

All hydrophones are synchronized with the GPS time few hours prior to their deployment and few hours after their recovery, so the internal clock drift, in the order of 10-7, can be precisely calculated. The clock drift is then linearly interpolated to correct the time stamp of each file. Note that the time stamps are in GPS time, not in UTC, and thus must be corrected for the leap seconds (GPS time was 16s ahead of UTC in 2014). Note also that the clock drift could not be determined for the hydrophones at MAD and SWAMS1 sites due to a power failure of the instruments prior to recovery.

All files pertinent to this study have been converted into CSS format in UTC time (data are stored in counts as little-endian integer 4).

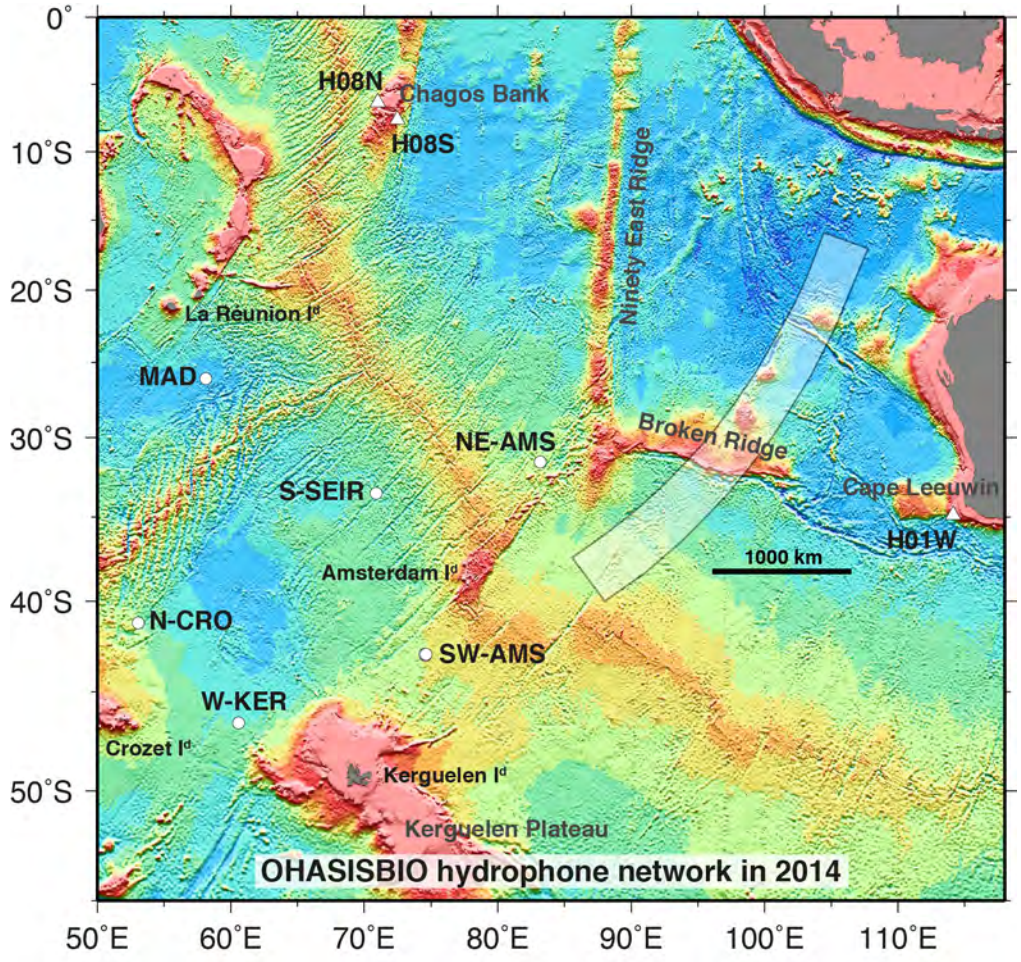


Figure 1 : Location of the OHASISBIO network of hydrophones (open circles) deployed in the southern Indian Ocean in 2014. Triangles show the location of the IMS-CTBTO permanent hydroacoustic stations. The shaded curved polygon outlines the presumed impact area of flight MH370 (after ATSB, 2014).

Location	Site	2014 mooring sites	Site depth [m]	Hydrophone depth[m]
North Crozet	N-CRO 3	053°05.05'E 41°14.93'S	3310	1050
West Kerguelen	W-KER 2	060°34.20'E 46°37.07'S	4530	970
Southwest Amsterdam	1	074°36.30'E 43°02.62'E	3450	1090
	SW-AMS 2	074°31.49'E 42°58.53'S	3460	1100
	3	074°37.77'E 42°57.53'S	3450	1090
Northeast Amsterdam ***[lost during recovery]***	*NE-AMS*	*083°11.36'E 31°34.12'S*	*3850*	*1090*
South Southeast Indian Ridge	S-SEIR	070°52.57'E 33°30.98'S	4180	1180
Madagascar Basin	MAD	058°08.40'E 26°04.99'S	5220	1260
Diego Garcia South	1	072.474438°E 07.645348°S		800
	H08S 2	072.493307°E 07.645545°S		800
	3	072.483879°E 07.627407°S		800
Cape Leeuwin	1	114.153979°E 34.892990°S		800
	H01W 2	114.134048°E 34.898071°S		800
	3	114.136304°E 34.882941°S		800

Table 1 : Location and depth of the OHASISBIO hydrophones moored in 2014 and the two permanent hydroacoustic stations of the IMS-CTBTO. All hydrophones are moored in the SOFAR channel axis.

Data analysis

In the search for clues of the MH370 impact with the ocean surface, several acoustic events were identified in the records of the H01W station, off Cape Leeuwin (Stead, 2014, ATSB, 2014, Curtin University, 2014). These events occurred after the last satellite handshake with the aircraft, that is after March 8, 2014, 00:19UTC (ATSB, 2014) and are shown in Figure 2. The Los Alamos report focuses on the event(s) near 00:52UTC (event S1) and recognizes two parts in the signal (Stead, 2014). The latter part provides good cross-correlations and a N190 direction for the source. This azimuth and the signal signature suggest an ice-related origin. The initial part of the signal is less coherent between the H01 hydrophones and only a tentative general direction WSW of the source relative to the H01 array could be determined. Curtin University examined the event at 01:34UTC (event S2) and located its source near the Chagos Laccadive Ridge (2.3˚S, 73.7˚E), so in a direction compatible with the presumed search area but at a distance that suggests that this event is not related to MH370 (ATSB, 2014, Curtin University, 2014, Butler, 2014).

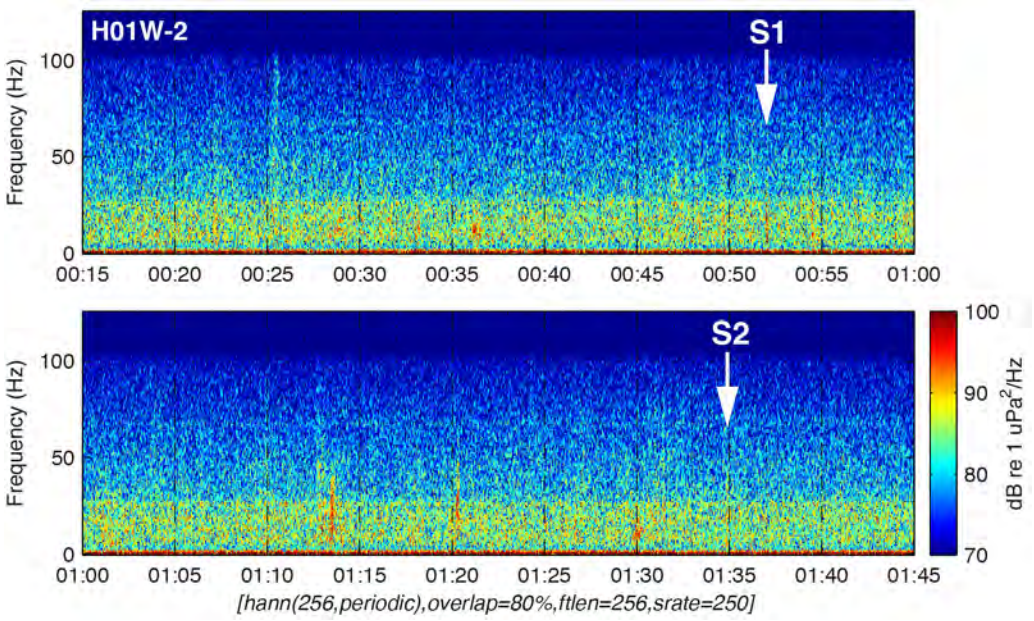


Figure 2 : Spectrogram of hydrophone H01W2 for March 8, 2014, from 00:15 to 01:45.
S1) Event analyzed by Stead (2014) ; S2) Event analyzed by Curtin University (ATSB, 2014, Curtin University, 2014, Butler, 2014)

We searched the OHASISBIO data for events that could be associated with these H01 events and found several candidates. The association being not unique, the inversion of the arrival times provides different plausible locations for the sources. The event arrival times were picked and inverted (i.e. triangulated) with the "Seas" analysis software developed by the Pacific Marine Environment Laboratory (Fox *et al.*, 2001). In a triangulation, the SWAMS and HO1W triplets will give confidence in the picked events but will not add much constraint to the inversion of time arrivals, since the hydrophones are very close from one another (10km and 2km, resp.). The large distances between hydrophones of the combined OHASIBIO-IMS network make cross-correlation techniques, generally used to process the data from the IMS triplets, inapplicable.

As mentioned earlier and noted in the Los Alamos report (Stead, 2014), the acoustic records west of 90˚E are obscured by long series of powerful seismic shots, 10s apart. Based on shot interruptions recognizable on several hydrophones, the exploration survey can be located in the Bay of Bengal, off the coast of Myanmar (Burma). The H01W triplet of hydrophones is exempt from this noise, due to the acoustic shade provided by the Indonesian islands and the submarine plateaus off western Australia. Some of the events in the OHASISBIO data have a higher energy than the seismic shots and thus can logically be attributed to geological or cryogenic sources (see Appendix). Some of these events match with those recognized in the H01W records. Weaker signals can also be found but are often difficult to identify on several hydrophones due to the size of the network and to the noisy acoustic environment.

We tentatively found 5 acoustic events occurring in the early hours of March 8, 2014 in the area of interest, between 00h16 and 01h06 UTC (Fig. 3). Two of them correspond to the events described in the Los Alamos report and by Curtin University (based on events S1 and S2 in Fig. 2, resp.). Two other acoustic events are identified on either side of the 90˚E Ridge near 26-28˚S. And the last event is located in the Diamantina Zone, southeast of Broken Ridge. However some of these solutions are mutually exclusive, since some share common hydrophone records in different site combinations. These five solutions are summarized in Table 3. All the detected events, including some earthquakes and cryogenic events, and their detection times are shown and listed in the Appendix.

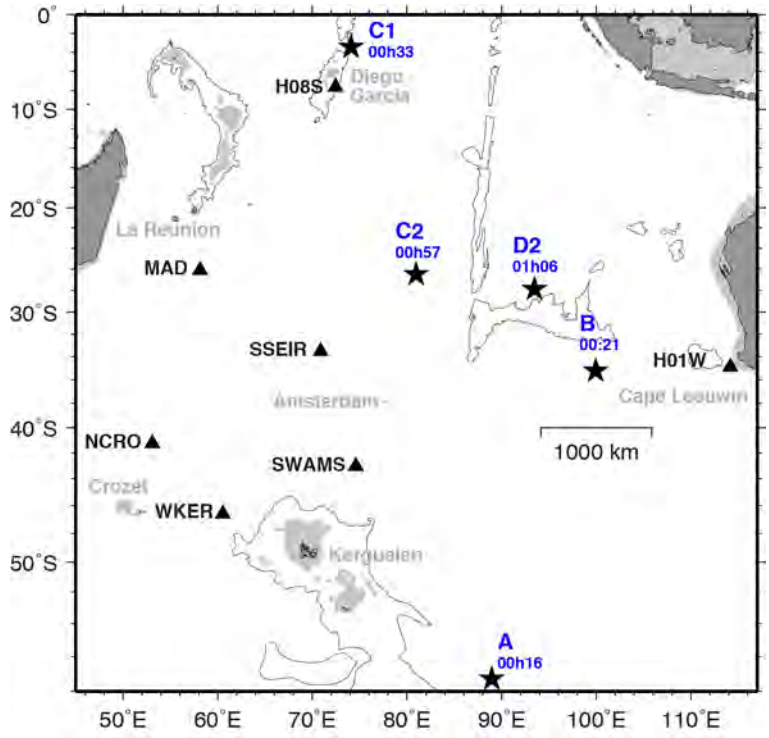


Figure 3 : Hydroacoustic events (stars) detected in the early hours of March 8, 2014 (UTC times) by the OHASISBIO and IMS hydrophones (triangles).

Event	Origin Time UTC	Latitude	Longitude	Err_lat [˚]	Err_lon [˚]	Err_time [s]	Nbr of hydrophones
A	00:16:29.4	-57.300	88.965	0.060	0.025	3.221	8
B	00:21:30.6	-35.224	99.922	0.076	0.022	1.533	7
C1	00:33:43.5	-3.445	74.087	0.117	0.025	7.447	6
C2	00:57:32.4	-26.469	80.952	0.038	0.015	2.075	8
D1	01:04:39.1	-25.404	93.567	0.071	0.014	3.448	7
D2	01:06:05.4	-27.856	93.460	0.047	0.007	1.439	6

Table 2 : Location and origin time of the events shown in Figure 3. Alternate events (C1-C2 or D1-D2) combine different sets of stations. Errors (err.) are standard errors. The number of hydrophones may look large, knowing that SWAMS and HO1W have each 3 hydrophones very close-by (10 & 2 km resp.).

As suspected by Stead (2014) from its acoustic signature at H01W, event A, at 57.3˚S 89.0˚E and 00h16 UTC, is likely due to an iceberg (Fig. 3 and 4). At four sites, one can recognized the same signal with frequencies from 5 to 45 Hz and duration of about 10s. Our location is consistent with the azimuth found by Stead from the H01W hydrophone triplet (N190). We identified similar events nearby at 23h47 UTC (March 7, 2014) and after 2 AM UTC (March 8). From an earlier hydroacoustic experiment in 2007, we located a very large collection of such icequakes in the same area (Royer *et al.*, 2015). The presence of icebergs is furthermore confirmed by visual observations in 2010 near 56˚S 80˚E; a series of large icebergs moving northwest-ward were spotted during RV *Marion Dufresne* cruise MD174. The basin southeast of the Kerguelen Plateau appears to be largely

populated by drifting icebergs during the austral summer and fall, caught in a large clockwise-rotating current loop (south of the main circum-antarctic polar current moving eastward).

The second identification, at 35.2˚S 99.99˚E and 00h16 UTC (event B), relies on a very tentative association of events, well defined on the nearest H01W stations, but hardly visible on the others (Fig. 5). The signal on H01W is low frequency (10-15 Hz) and lasts about 30s. An alternate association combines the OHASISBIO events with a shorter event at 00h33 on H01W (10s) and leads to a location nearby (35.14˚S 101.42˚E) and an origin time of 00h20 UTC. Still both source events would be too distant from the assumed location of the MH370 aircraft at the time of its last satellite handshake at 00h19 UTC.

The third solution C1, at 3.4˚S 74.1˚E and 00h33 UTC, on the edge the Chagos Bank, matches the solution found by Curtin University (ATSB, 2014, Curtin University, 2014). In the OHASISBIO acoustic data, the signatures of this event are rather weak and obscured by seismic shots (Fig. 6). Although only located 270km away from the H08S stations, this event is indistinguishable from the seismic shots in the H08S data and possibly shaded by the Chagos Bank.

We found an alternate combination of records, based on the same H01W event at 01h34 UTC (event S2 in Fig. 2), that places the source event west of the 90˚E Ridge, at 26.5˚S 80.9˚E and at a later time 00h57 UTC (event C2 in Fig. 3; Fig. 7). The associated events on SSEIR and SWAMS better resemble the signature observed on H01W (Fig. 7) than in solution C1 (Fig. 6). This solution is off the azimuth and uncertainty region determined from the H01W triplet (ATSB, 2014, Curtin University, 2014). IMS hydroacoustic triplets generally provide very precise azimuth for the acoustic sources relative to the triplets, while poorly resolving its distance from the hydrophones. In any case, solutions C1 and C2 are mutually exclusive. We favor solution C2 as the event signatures on the different hydrophones better match than in the C1 association. In addition, errors are smaller in the C2 determination than for C1. There is even a fourth way to combine the 01h34 UTC event on H01W with different events on SWAMS and SSEIR pointing to an event in the vicinity of event A (see Table 5 in the Appendix). But we discarded this solution due the very large error in the time origin (up to 46s).

The last identification, at 27.9˚S 93.6˚E and 01h06 UTC (event D2), is again uncertain (Fig. 8). It is based on an event record on H01W that lasts more than 15s (starting at about 01:29:45 UTC), whereas the associated events on the other hydrophones are shorter (< 10s) but consistent with one another (NCRO, SEIR, MAD). The source event is nearly at the same distance of H01W and SWAMS, so it is unclear why its low-frequency acoustic signature would be so different (duration and shape), casting some doubt on this association of events. No events are detected on SSEIR and WKER, perhaps acoustically shaded by Broken Ridge (Fig. 1). There is an alternate solution (D1), giving a location 2 degrees north of D2 at 25.4˚S 93.6˚E and a similar time origin (01h04) but with a larger error. We favor the former solution since it is based on a wider geometry of hydrophones (i.e. geographically better distributed).

Conclusion

In conclusion, the OHASISBIO hydroacoustic data do not unambiguously resolve the enigma of the impact site of flight MH370. We propose two tentative locations C2 and D2 subject to high uncertainties due to the difficulty of identifying a likely weak acoustic signature in a noisy environment, obscured by series of energetic seismic shots, and to the non-uniqueness of the event association. Unfortunately also, the OHASISBIO hydrophone closest to the presumed impact area (NEAMS) was lost during its recovery. Although D2 is in the vicinity of the presumed impact area, this event, as C2, are in seismically active areas according to teleseismic catalogs, due to the on-going deformation of the Indo-australian plate (e.g. Royer and Gordon, 1997).

Among previously proposed solutions, we can attribute the southernmost location A near 56˚S 89˚E to a cryogenic event (event at 00h52 UTC on H01W).

For all these reasons, as stated in the introduction, **the inferred locations must be considered with extreme caution, and even if correct, we cannot tell whether these acoustic events are related to the disappearance of flight MH370.**

Appendix

The appendix provides:

- The sensitivity of the OHASISBIO hydrophones.
- A map and list of all the events detected between 23h45 (March 7) and 02h00 UTC (March 8) and the event arrival times to the hydrophones used in the triangulations.
- The full spectrograms from 00h to 02h UTC (March 8, 2014) for the hydrophones closest to the presumed impact area: SWAMS-3, SSEIR and H01W-2.

Acknowledgements

The deployment and recovery cruises of the hydrophones with RV *Marion Dufresne* were funded by the French Polar Institute (Institut Polaire Français Paul Emile Victor): cruises VT135/OHA-SIS-BIO-6 (http://doi.org/10.17600/14002600) and VT141/OHA-SIS-BIO-7 (http://doi.org/10.17600/15003100). The OHASISBIO experiment benefited from additional support from INSU-CNRS. The equipment (moorings and instruments) was funded by Région Bretagne (CPER ODO) and INSU-CNRS.

Disclaimer

The findings presented in this report only represent the view of the author. The CNRS and the University of Brest neither endorse the viewpoint of this publication nor guarantee its technical correctness.

Acronyms

ATSB	Australian Transport Safety Bureau (https://www.atsb.gov.au/mh370/)
BEA	Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (https://www.bea.aero)
CNRS	Centre National de la Recherche Scientifique (http://www.cnrs.fr)
CPER-ODO	Contrat de projets Etat-Région – Observatoire des Domaines Océaniques
CSS	Center for Seismic Studies CSS format description: http://geophysics.eas.gatech.edu/GTEQ/Scream4.4/File_Format_CSS.htm
CTBTO	Comprehensive Test Ban Treaty Organization (https://www.ctbto.org)
IMS	International Monitoring System (https://www.ctbto.org)
INSU	Institut National des Sciences de l'Univers of CNRS (http://www.insu.cnrs.fr)
IPEV	Institut Polaire Français Paul Emile Victor (http://www.institut-polaire.fr/language/en/)
OHASISBIO	Observatoire HydroAcoutique de la SISmicité et de la BIOdiversité https://www-iuem.univ-brest.fr/ldo/fr/Observation/marine/hauturiere

References

ATSB, 2014. MH370 - Definition of underwater search areas. *Australian Transport Safety Bureau*, Report: AE-2014-054 (26 June 2014).

Butler, D., 2014. Sound clue in hunt for MH370. *In Nature*, pp. 199-200.

Curtin University, 2014. Curtin researchers in search for acoustic evidence of MH370. In Media release C067/2014 (4 June 2014), pp. 6.

D'Eu, J.-F., Royer, J.-Y. & Perrot, J., 2012. Long-term autonomous hydrophones for large-scale hydroacoustic monitoring of the oceans. *In Proceedings of Oceans 2012*, pp. 1-6, IEEE, Yeosu (Korea).

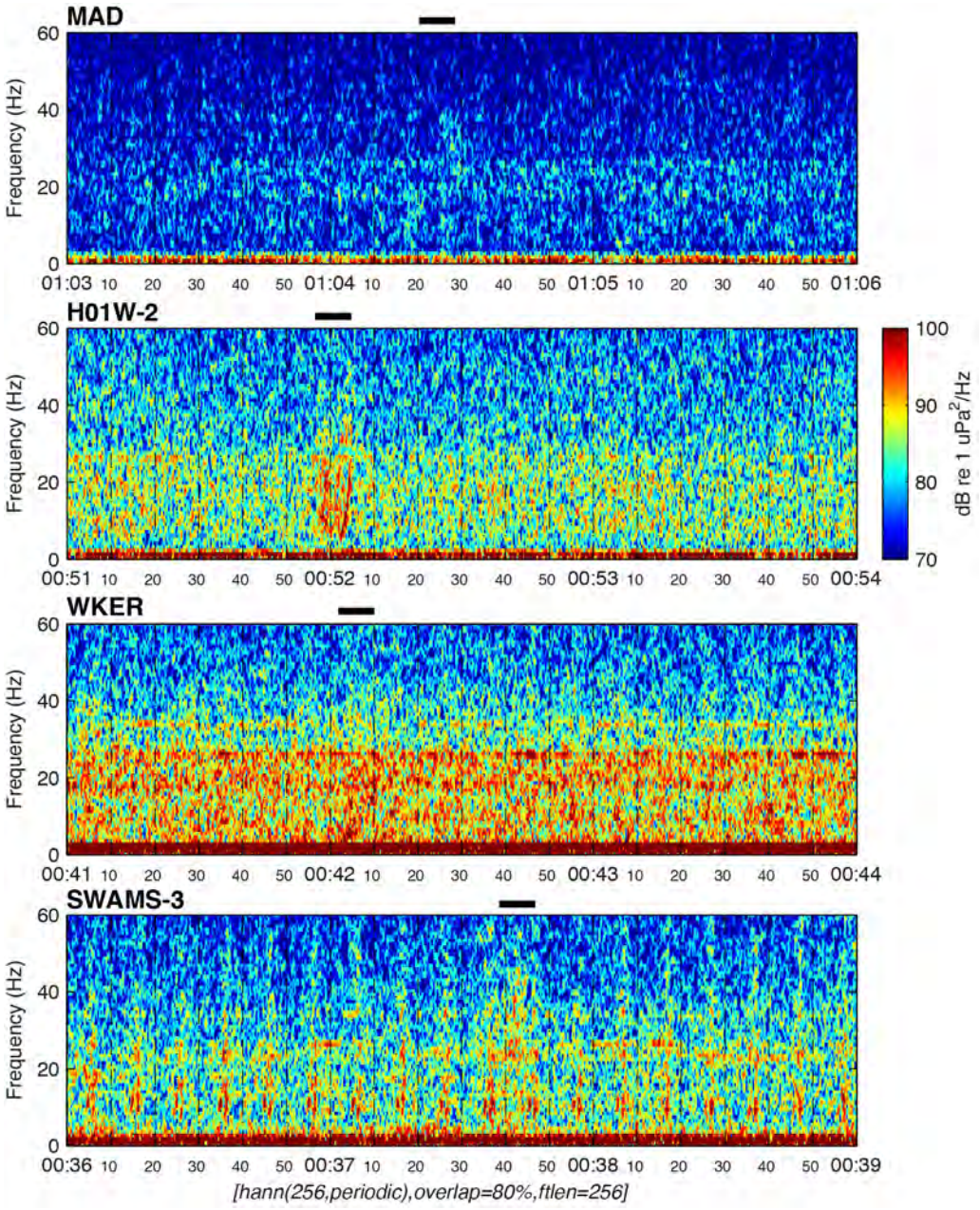
Fox, C.G., Matsumoto, H. & Lau, T.-K.A., 2001. Monitoring Pacific Ocean seismicity from an autonomous hydrophone array, *J. Geophys. Res.,* 106**,** 4183-4206.

Royer, J.-Y. & Gordon, R.G., 1997. The motion and boundary between the Capricorn and Australian plates, *Science,* 277**,** 1268-1274.

Royer, J.-Y., Chateau, R., Dziak, R.P. & Bohnenstiehl, D.R., 2015. Seafloor seismicity, Antarctic ice-sounds, cetacean vocalizations and long-term ambient sound in the Indian Ocean basin, *Geophys. J. Int.,* 202**,** 748-762.

Stead, R.J., 2014. Seismic and hydroacoustic analysis relevant to MH370. *Los Alamos National Laboratory*, Report: LA-UR-14-24972, pp. 16.

.



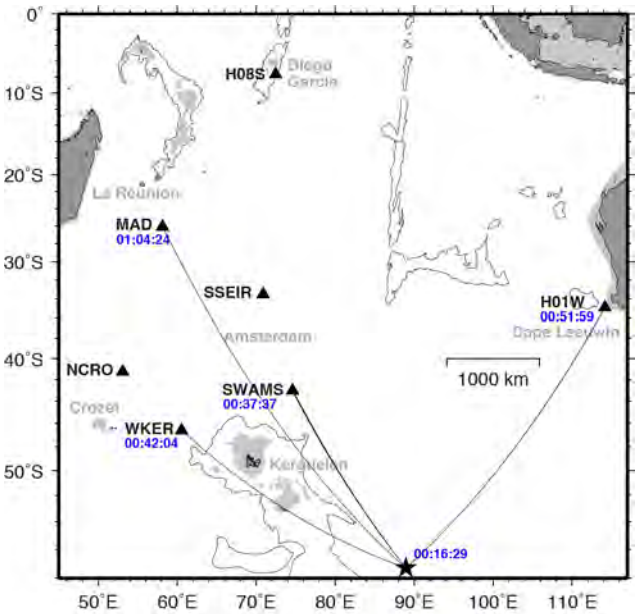
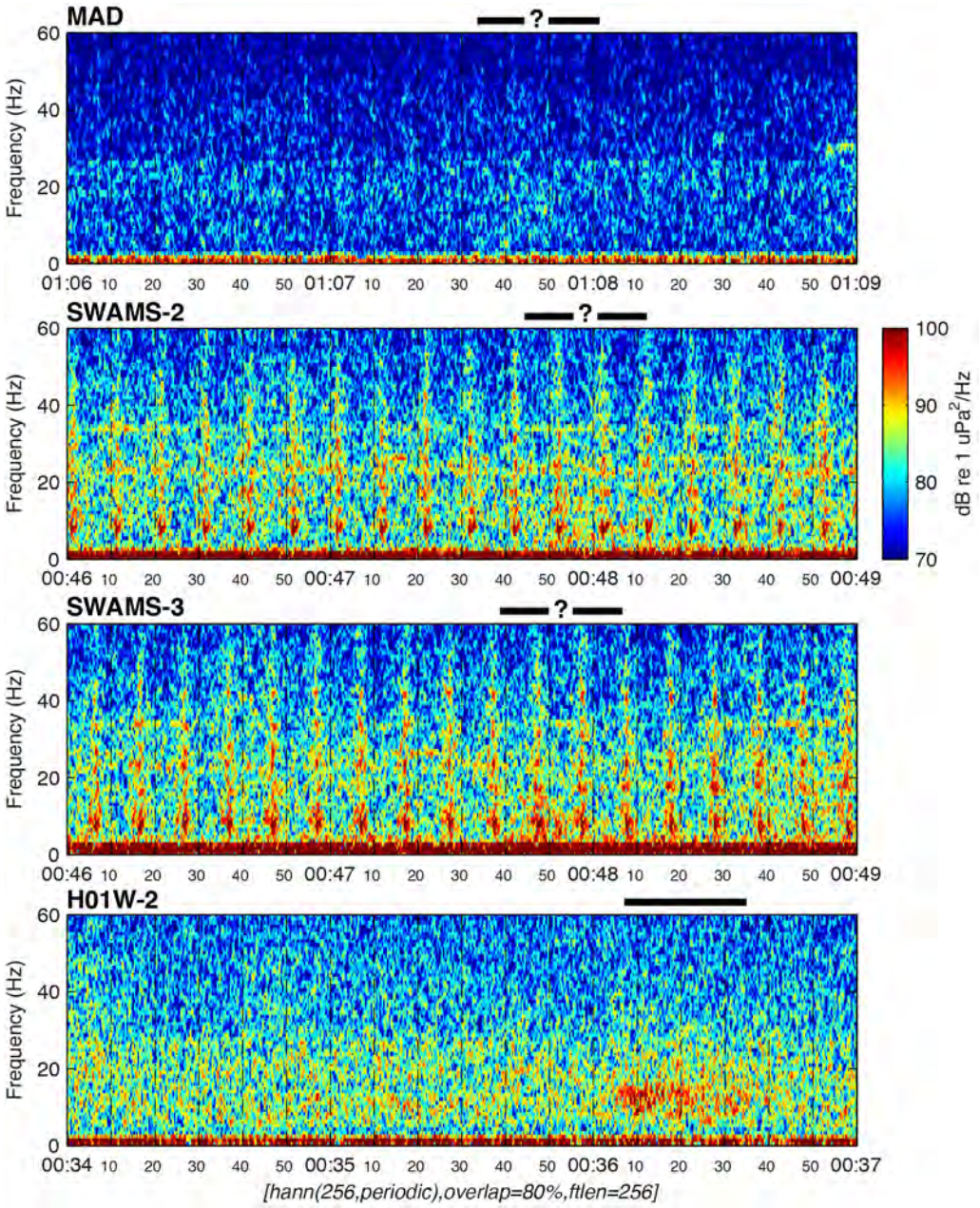


Figure 4: Tentative association of records locating an acoustic source event east of the Kerguelen Plateau at 00h16 UTC (08/03/2014). Based on the event observed at 00h52 on H01W.

Seismic shots are clearly visible on SWAMS-3.



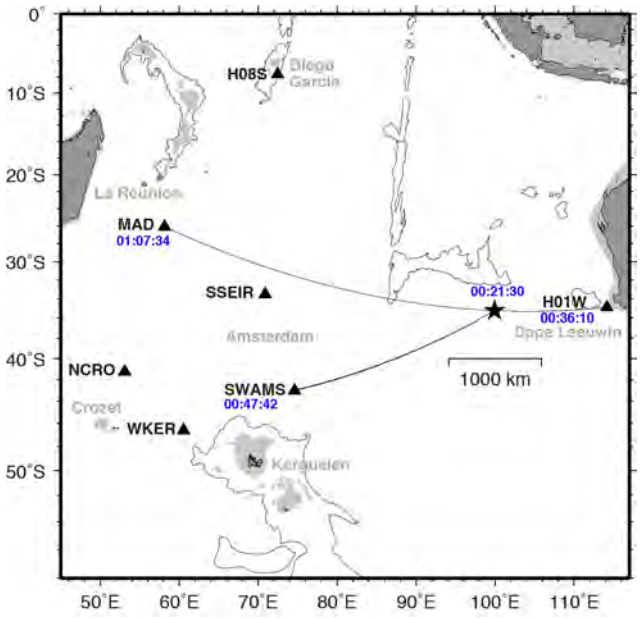
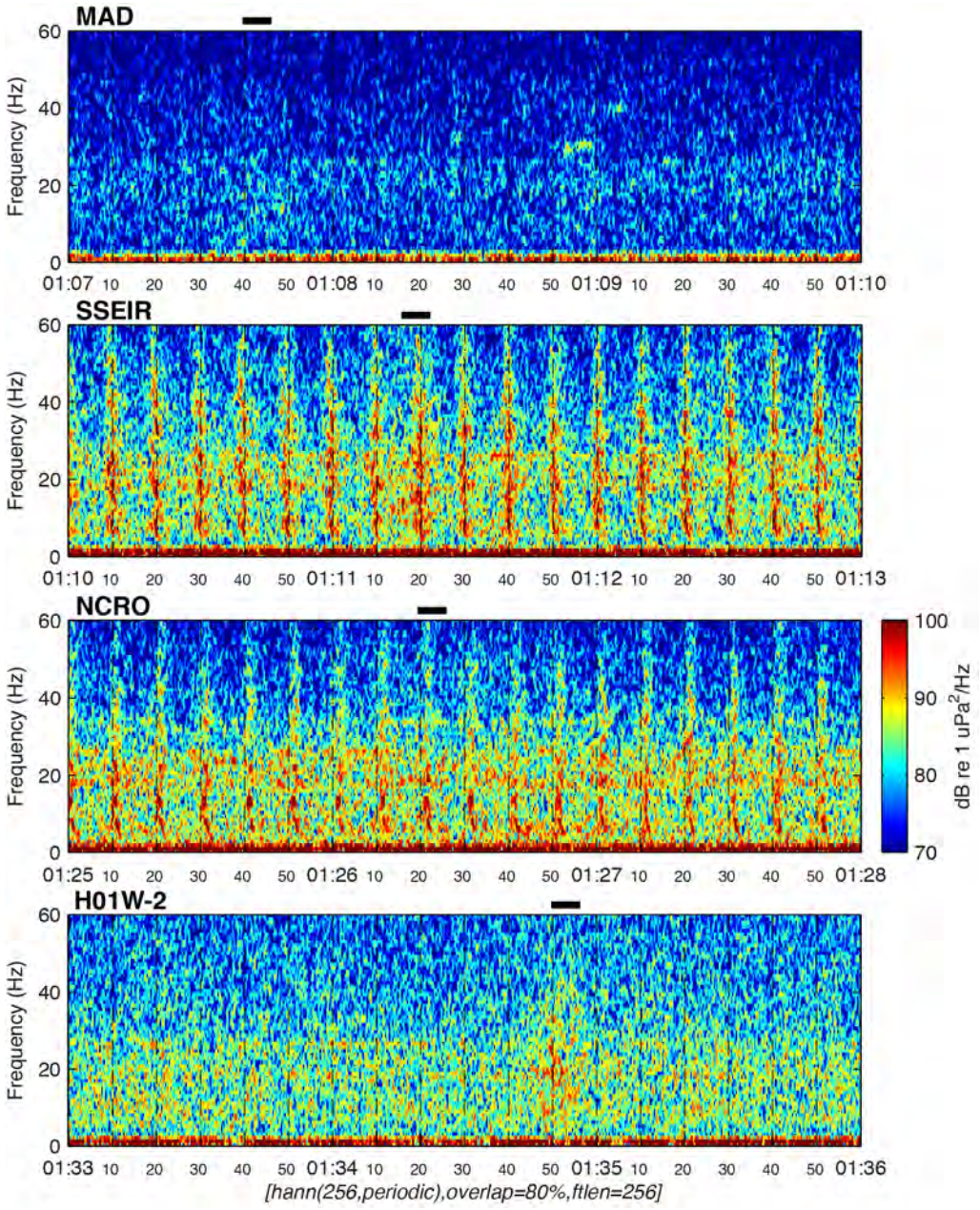


Figure 5: Tentative association of records placing the acoustic source southeast of Broken Ridge at 00h21 UTC (08/03/2014). Based on the event observed at 00h36 on H01W.

Seismic shots obscure the SWAMS site.



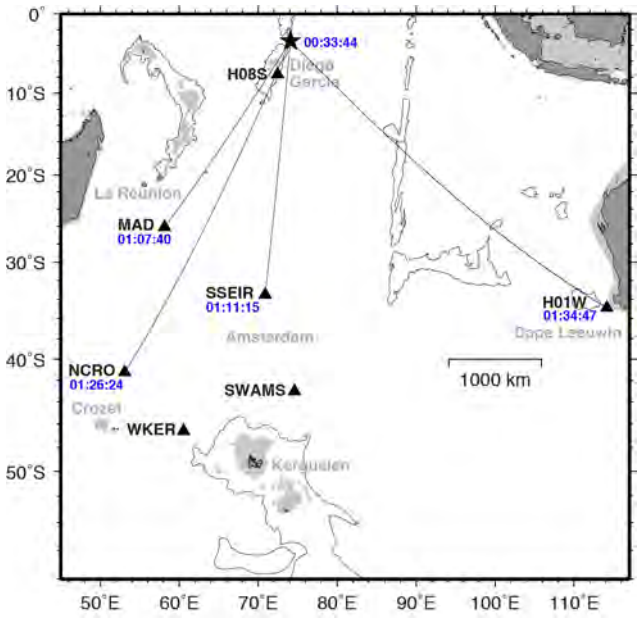
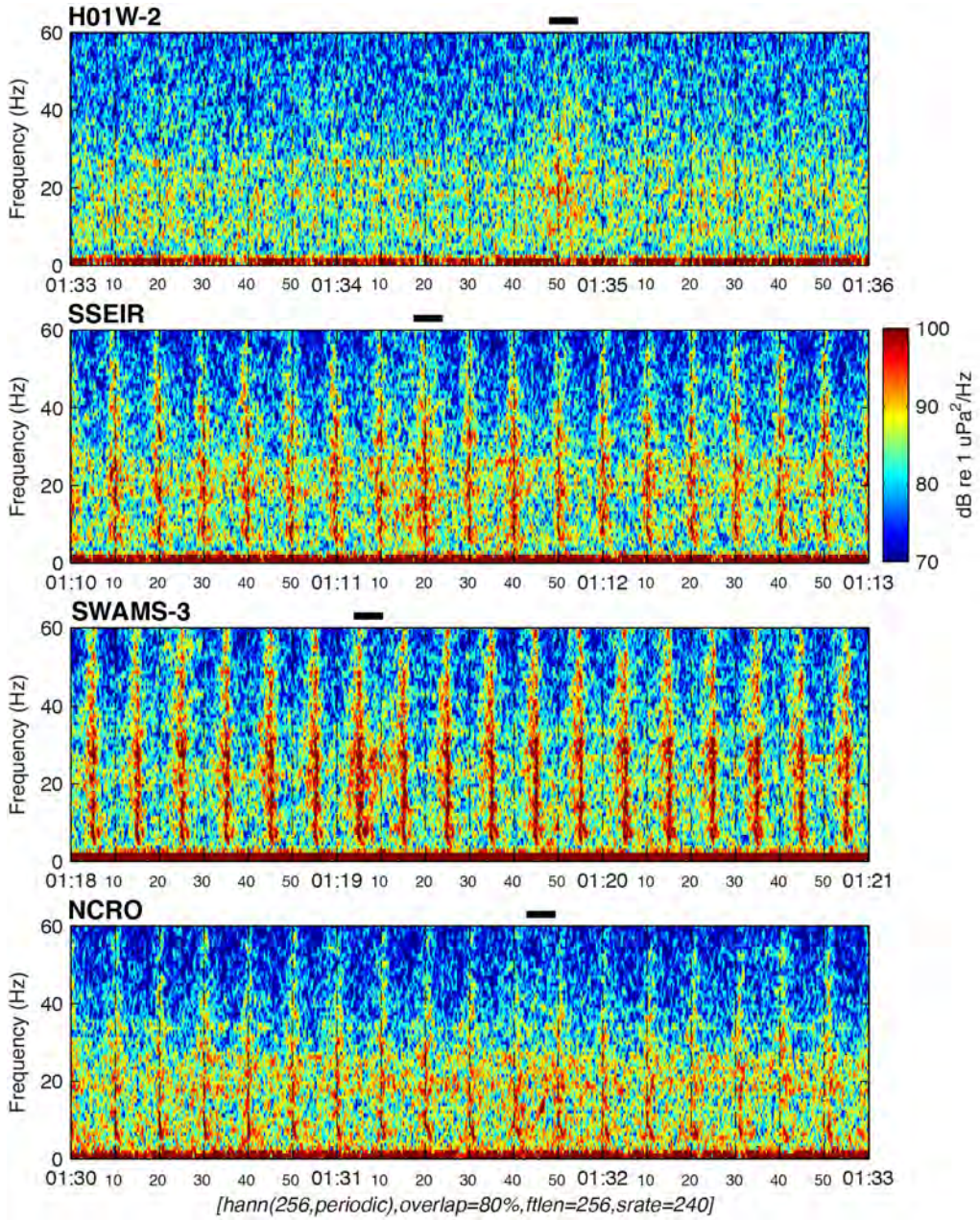


Figure 6: Tentative association of records placing the acoustic source north of Diego Garcia Island at 00h33 UTC (08/03/2014). Based on the event observed at 01h34 on H01W.

Seismic shots obscure the NCRO and SSEIR records.



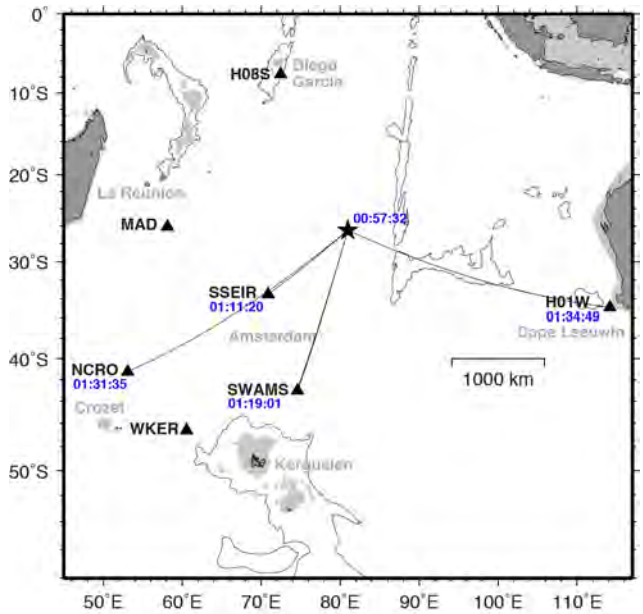
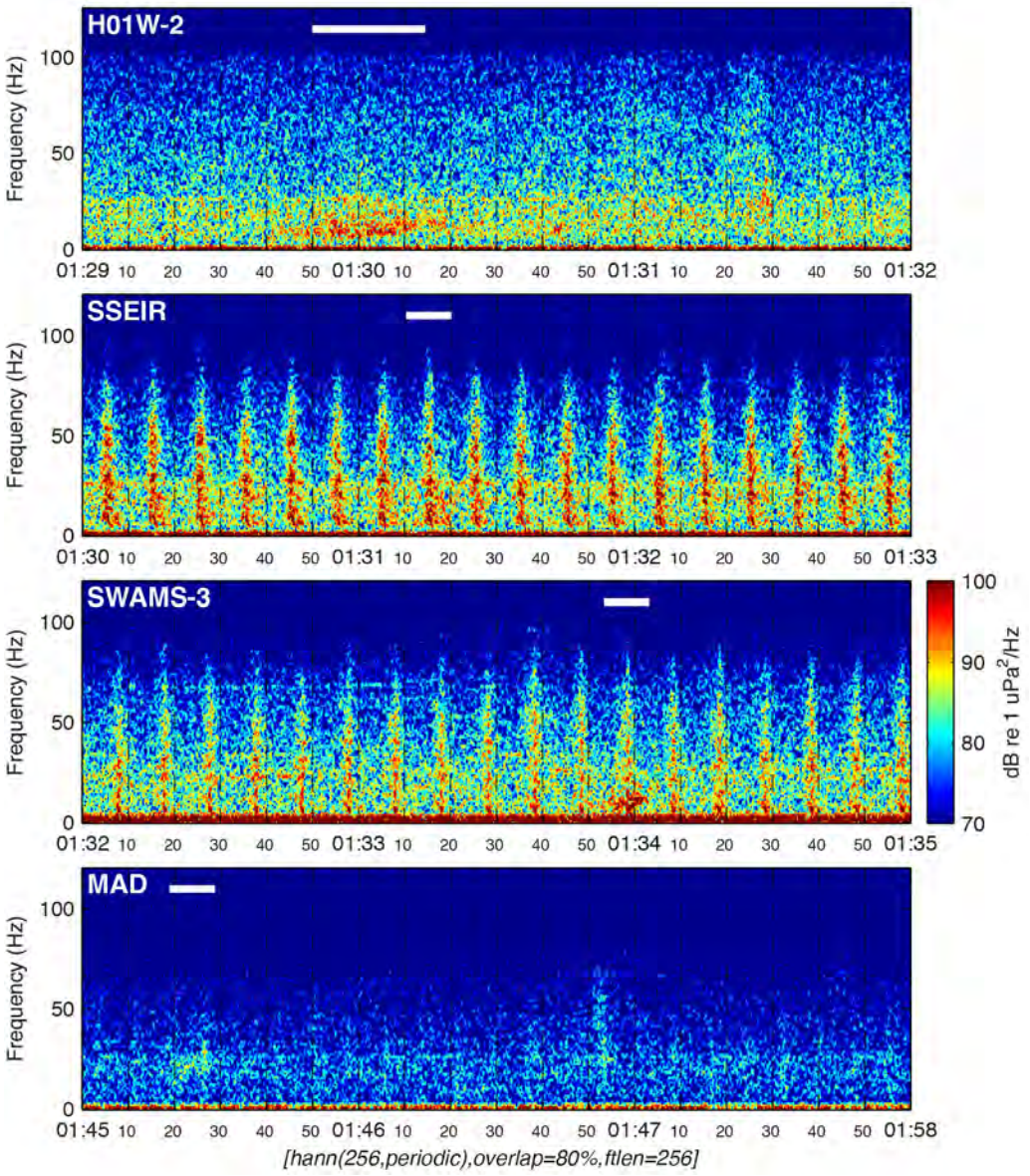


Figure 7: Alternate association of records placing the acoustic source west of the 90E Ridge at 00h57 UTC (08/03/2014). Based on the same event observed at 01h34 on H01W as in Fig. 6.

Seismic shots obscure the NCRO, SWAMS-3 and SSEIR records.



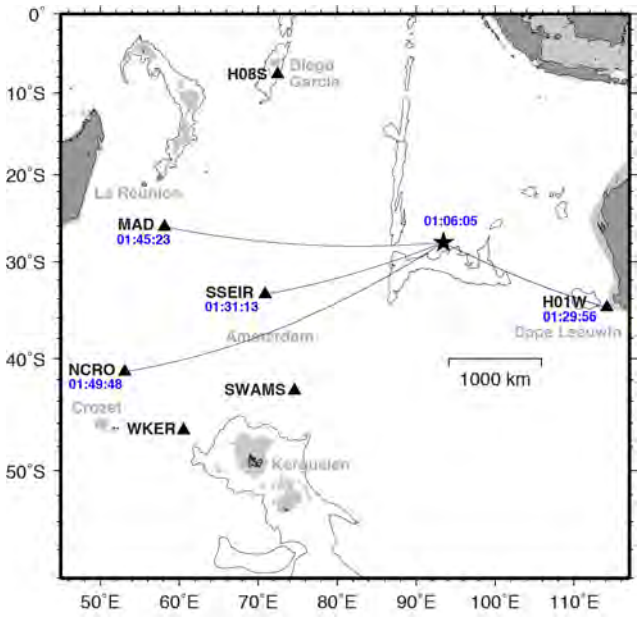


Figure 8: Tentative association of records locating the acoustic source east of 90E Ridge at 01h06 UTC (08/03/2014). Based on an event observed at 01h30 on H01W.

Seismic shots obscure the SWAMS-3 and SSEIR records.

Appendix

Site	NCRO	WKER	SWAMS 1-2-3	SSEIR	MAD	H08S	H01
µV/count	0.298	0.298	0.298	0.298	0.298	0.848	0.848
dB re: 1 µPa/V	-164	-164	-164	-164	-164	-174	-174

Table 3 : Conversion factor and sensitivity of the OHASISBIO hydrophones

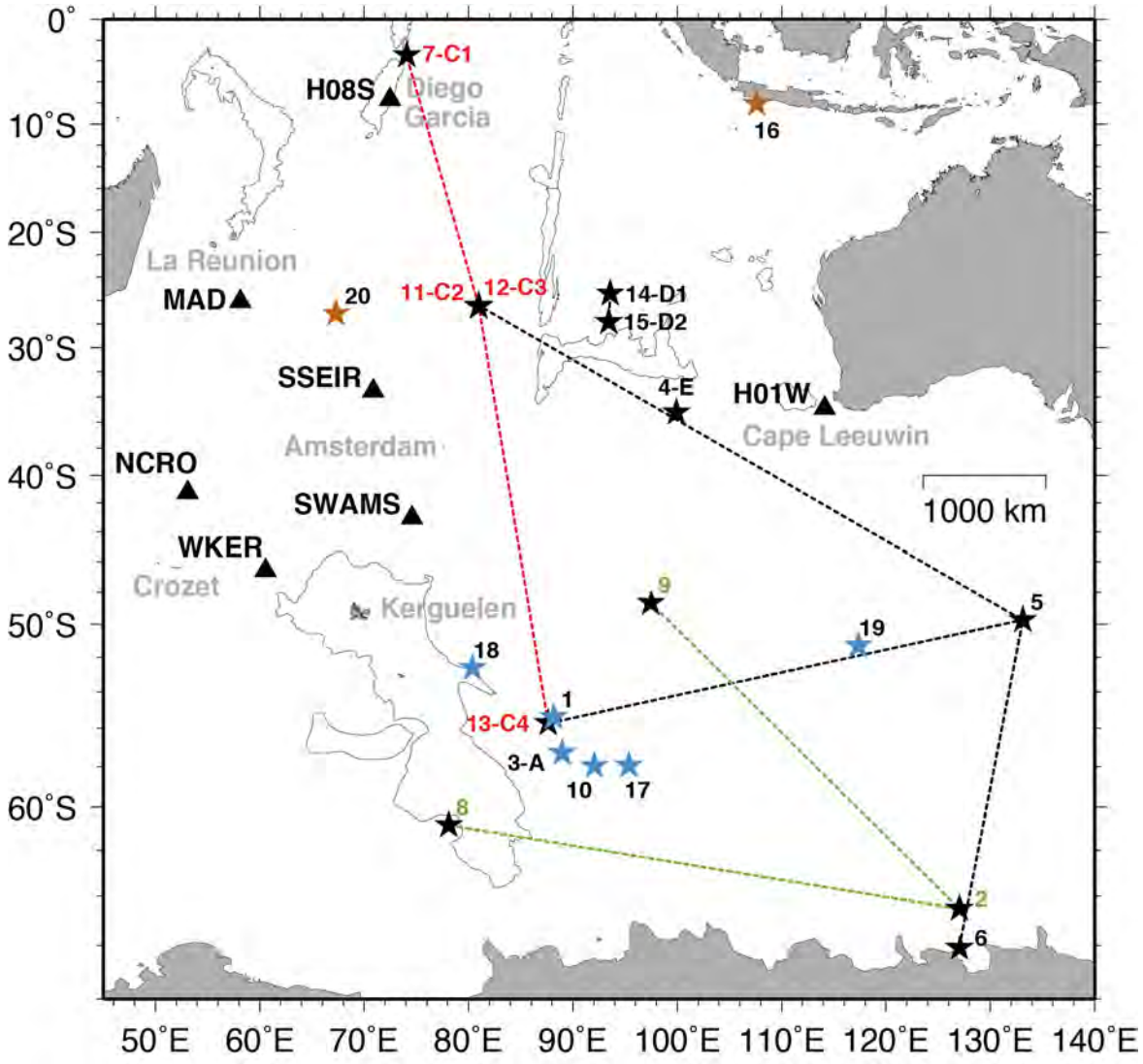


Figure 9 : Acoustic events (stars) located with the OHASISBIO and IMS-CTBTO hydrophones (triangles) between 23h45 UTC (March 7, 2014) and 02h05 UTC (March 8, 2014). Numbers refer to the indexed list in Tables 4 and 5.

Earthquakes (16, 20) are in brown, cyrogenic events (1, 3, 10, 17, 18, 19) in blue.

Color-coded events, linked by dashed lines, are mutually exclusive, since they are based on some common records in different combinations of sites (see Table 5).

Index	Type of event	Origin Time UTC	Latitude	Longitude	Err_lat [°]	Err_lon [°]	Err_time [s]	Nbr of stations
1	Icequake	23:47:46.2 (*)	-55.400	88.173	0.219	0.036	11.348	7
2	Uncertain	00:13:09.3	-64.510	127.048	1.619	4.504	99.999	6
3	A icequake	00:16:29.4	-57.300	88.965	0.060	0.025	3.221	8
4	B	00:21:30.6	-35.224	99.922	0.076	0.022	1.533	7
5	Uncertain	00:28:51.5	-49.755	133.114	0.213	1.354	61.139	7
6	Uncertain	00:32:49.2	-66.090	127.043	0.018	0.041	0.334	6
7	C1 Unc.	00:33:43.5	-3.445	74.087	0.117	0.025	7.447	6
8	Uncertain	00:36:21.8	-60.844	78.097	0.216	0.202	15.099	7
9	Uncertain	00:37:52.4	-48.671	97.477	0.045	0.023	1.583	8
10	Icequake	00:56:45.5	-57.967	92.050	0.394	0.035	21.666	7
11	C2 Unc.	00:57:32.4	-26.469	80.952	0.038	0.015	2.075	8
12	C3 Unc.	00:57:33.5	-26.539	80.979	0.127	0.050	6.929	8
13	C4 Unc.	00:59:55.3	-55.719	87.615	0.866	0.195	46.771	7
14	D1 Unc.	01:04:39.1	-25.404	93.567	0.071	0.014	3.448	7
15	D2 Unc.	01:06:05.4	-27.856	93.460	0.047	0.007	1.439	6
16	Earthquake	01:15:48.0	-8.052	107.622	0.067	0.024	4.706	9
17	Icequake	01:37:39.5	-57.950	95.354	0.062	0.028	3.468	8
18	Icequake	01:49:33.0	-52.635	80.389	0.193	0.121	10.832	8
19	Icequake	01:58:14.2	-51.322	117.339	0.381	0.713	33.969	7
20	Earthquake	02:02:31.7	-27.149	67.307	0.062	0.050	3.426	6

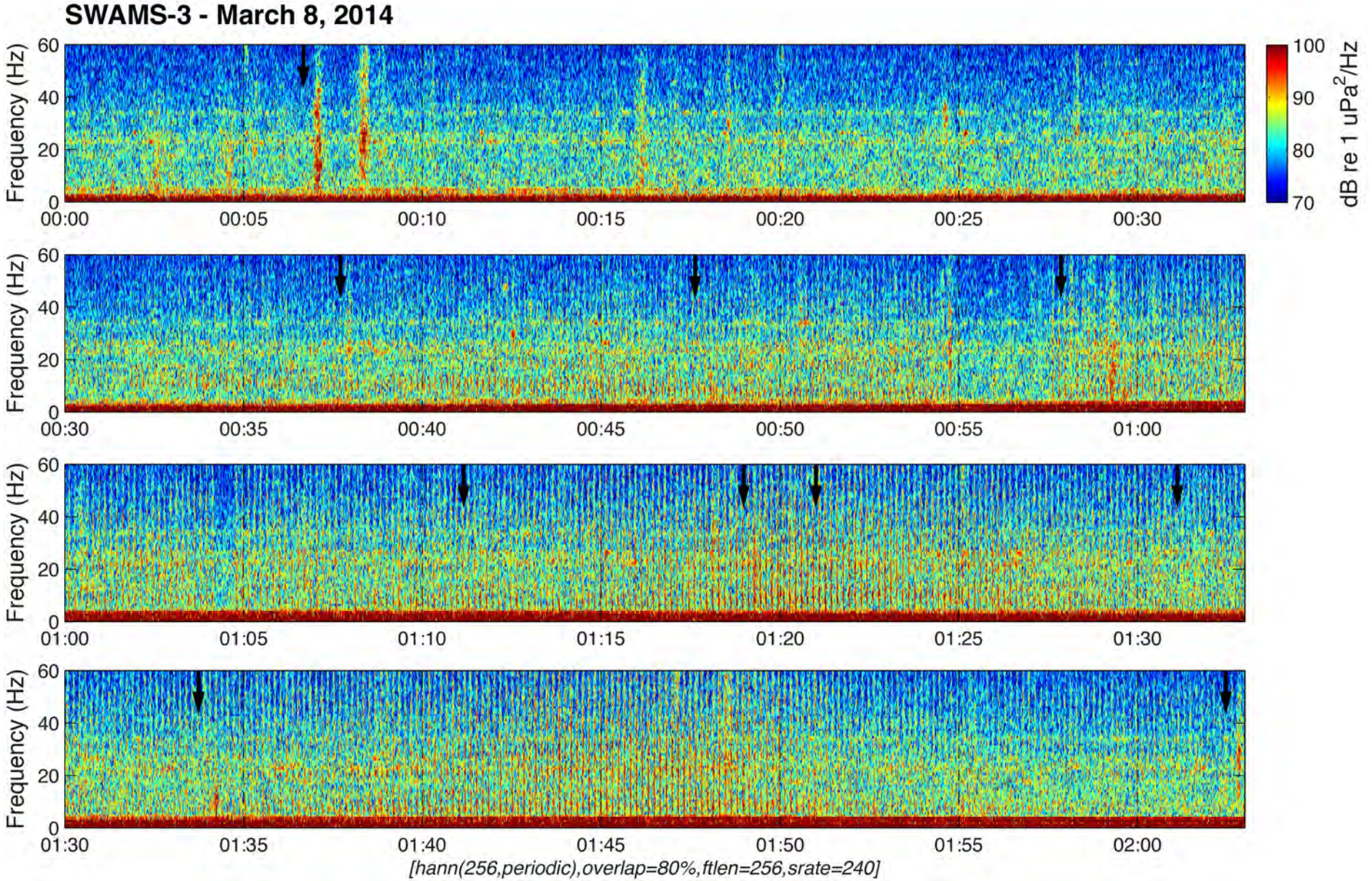
Table 4 : List of events jointly detected by the OHASISBIO and the IMS-CTBTO hydrophones, at the end of March 7, 2014 (*) and in the early hours of March 8, 2014. Alternate events (C1,2,3,4 and D1,2) combine different sets of stations. Errors (err.) are standard errors.

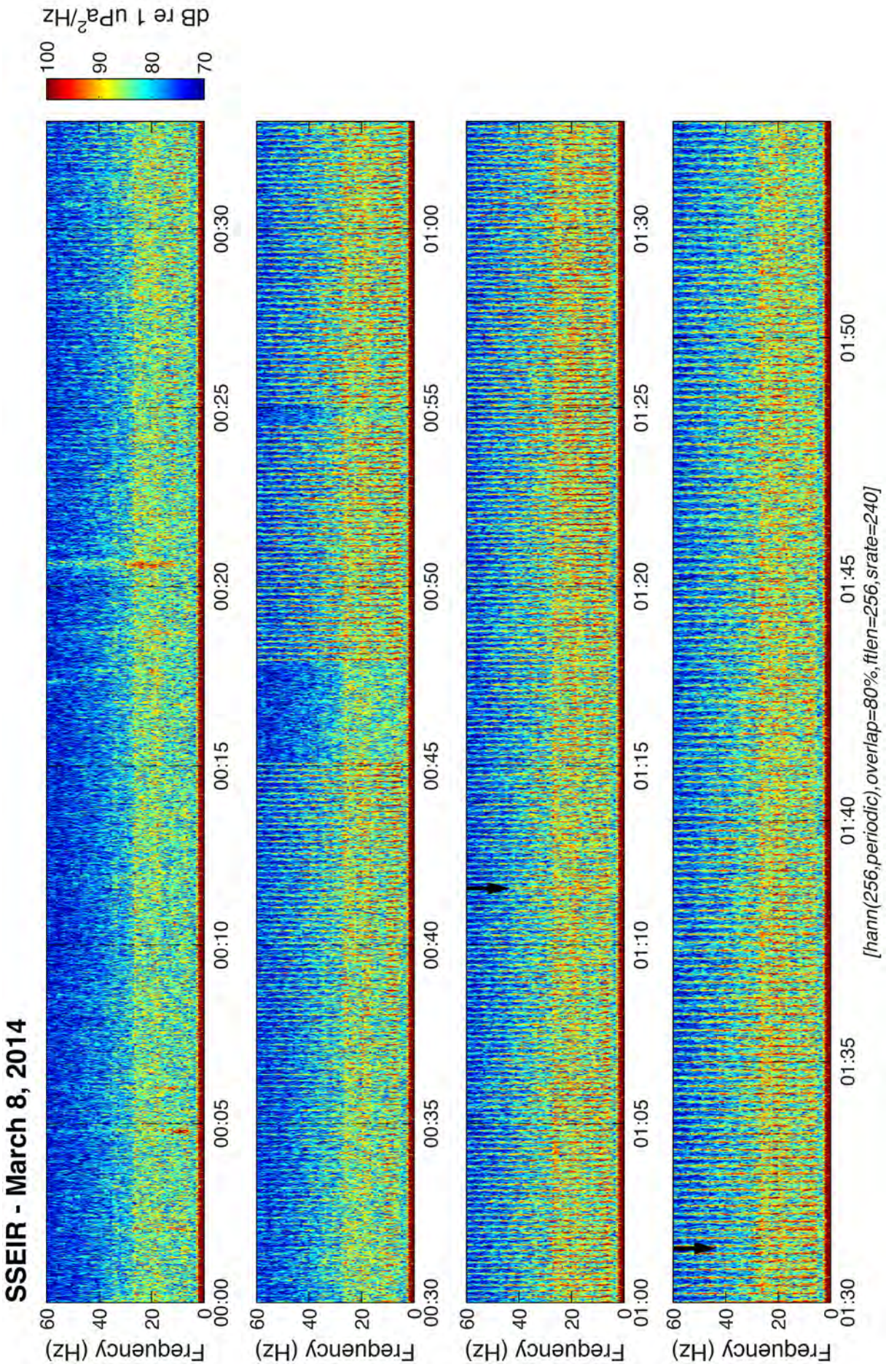
Note that SWAMS and HO1W have each 3 hydrophones very close-by (10 and 2 km resp.), which give confidence in the picked events but do not add much constraint in the inversion. The high uncertainties in the origin time (shaded boxes on the right) question the reliability of the solution. Some solutions (shaded boxes on the left) are mutually exclusive, since some share common events in different combinations of sites (see next table).

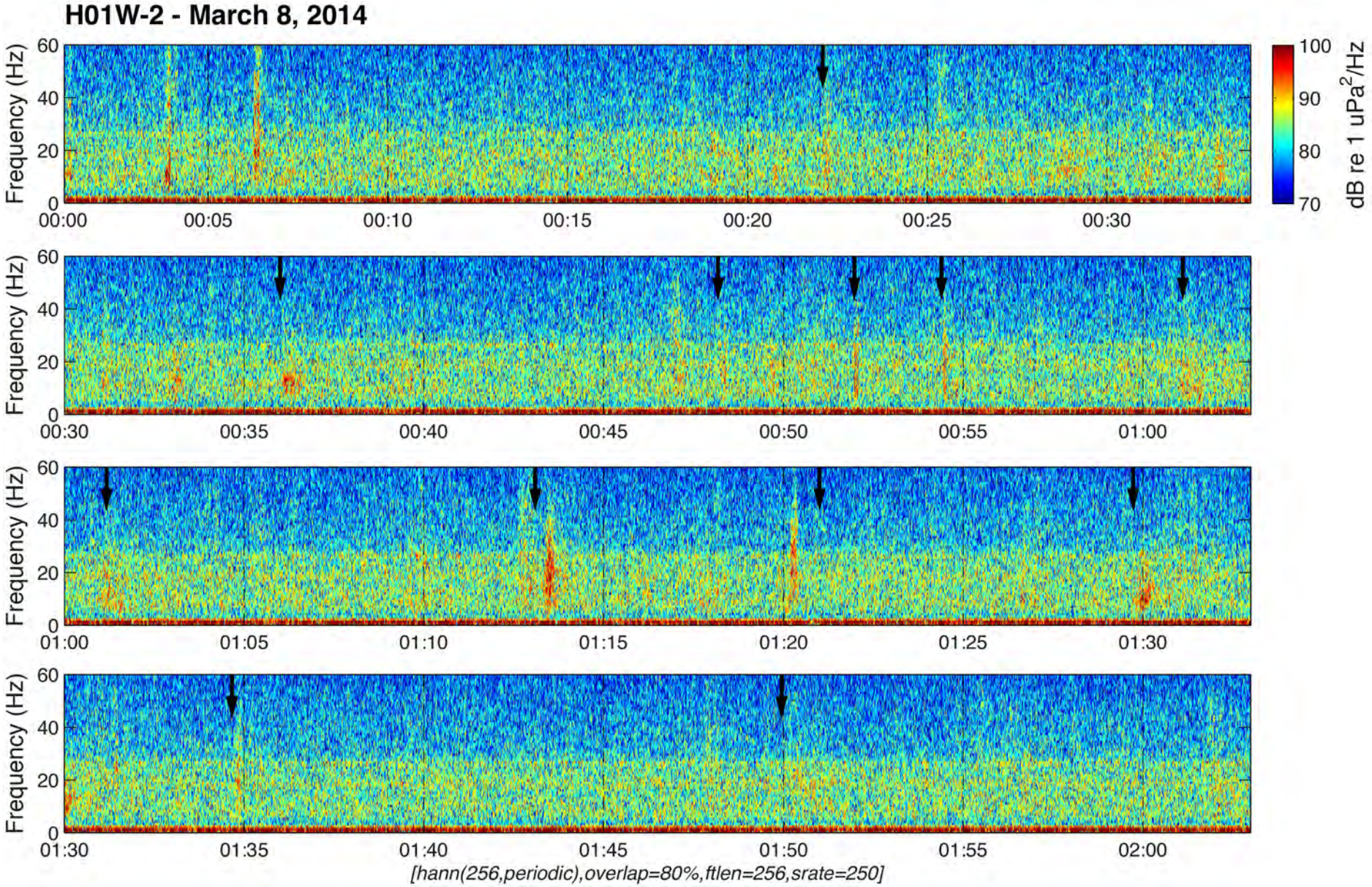
Index	Event type	Origin time	MAD	NCRO	WKER	SSEIR	SWAMS1	SWAMS2	SWAMS3	H01W1	H01W2	H01W3
1	Icequake	23:47:46.2	00:33:34.57	X	X	X	00:06:40.95	00:06:49.43	00:06:45.88	00:21:50.93	00:21:50.93	00:21:48.94
2	Uncertain	00:13:09.3	X	X	X	X	00:58:54.02	00:58:54.08	00:58:54.68	00:51:38.62	00:51:38.62	00:51:38.62
3	A icequake	00:16:29.4	01:04:24.70	X	00:42:04.65	X	00:37:37.22	00:37:45.64	00:37:42.15	00:51:42.99	00:51:40.99	00:51:42.99
4	B	00:21:30.6	01:07:34.30	X	X	X	00:47:42.69	00:47:44.00	00:47:38.95	00:35:54.76	00:35:44.00	00:35:54.71
5	Uncertain	00:28:51.5	01:45:19.24	X	X	X	01:18:55.09	01:19:01.48	01:18:59.88	00:54:10.39	00:54:08.45	00:54:12.44
6	Uncertain	00:32:49.2	X	X	X	X	01:18:53.62	01:19:03.48	01:18:58.15	01:13:12.04	01:13:12.04	01:13:10.05
7	C1 Unc.	00:33:43.5	01:07:41.64	01:26:24.17	X	01:11:15.87	X	X	X	01:34:31.19	01:34:29.19	01:34:33.13
8	Uncertain	00:36:21.8	X	X	X	01:11:10.16	00:58:44.00	00:58:56.56	00:58:56.95	01:19:58.74	01:19:56.74	01:19:56.74
9	Uncertain	00:37:52.4	01:25:20.44	X	01:09:00.07	X	00:58:44.00	00:58:58.55	00:58:54.81	01:00:51.91	01:00:51.86	01:00:53.85
10	Icequake	00:56:45.5	01:46:44.00	X	X	X	01:19:44.00	01:20:03.21	01:20:01.61	01:31:04.39	01:31:04.39	01:31:06.39
11	C2 Unc.	00:57:32.4	X	01:31:35.91	X	01:11:20.83	01:19:01.49	01:19:01.34	01:18:57.75	01:34:33.24	01:34:33.24	01:34:33.24
12	C3 Unc.	00:57:33.5	X	01:31:41.91	X	01:11:16.83	01:18:55.49	01:18:57.21	01:18:57.61	01:34:31.24	01:34:31.19	01:34:29.19
13	C4 Unc.	00:59:55.3	X	X	X	01:31:17.35	01:18:57.09	01:19:03.48	01:18:44.00	01:34:33.18	01:34:33.18	01:34:33.18
14	D1 Unc.	01:04:39.1	X	X	X	01:31:11.36	01:33:51.22	01:33:55.21	01:33:49.48	01:29:42.47	01:29:40.42	01:29:40.42
15	D2 Unc.	01:06:05.4	01:45:23.37	01:50:28.57	X	01:31:13.36	X	X	X	01:29:42.37	01:29:42.37	01:29:40.37
16	Earthquake	01:15:48.0	02:18:44.57	02:28:55.37	X	02:08:46.29	02:12:30.29	02:12:30.29	02:12:24.55	01:50:01.40	01:49:59.40	01:49:57.41
17	Icequake	01:37:39.5	X	02:17:17.11	X	02:14:37.58	02:02:24.15	02:02:34.54	02:02:31.08	02:10:33.88	02:10:31.88	02:10:33.88
18	Icequake	01:49:33.0	02:28:46.04	X	X	02:14:46.80	02:02:22.15	02:02:28.55	02:02:29.08	02:26:48.73	02:26:48.73	02:26:48.73
19	Icequake	01:58:14.2	03:02:19.77	X	X	X	02:35:34.42	02:35:38.68	02:35:39.08	02:18:53.49	02:18:51.50	02:18:51.55
20	Earthquake	02:02:31.7	02:12:39.64	02:25:15.77	X	02:11:08.93	02:23:33.75	02:23:25.36	02:23:24.01	X	X	X

Table 5 : Arrival times (UTC) at each hydrophone of the OHASISBIO and IMS-CTBTO network. X denote stations that were not used in the inversion, generally due to the lack of any recognizable signal.

Note that the event at 01:34:30 UTC on H01W (shaded boxes), combined with different events on the other hydrophones, point to quite different locations (C1-2-3-4), outlining the difficulty of associating events (the same occurs for the events 00:58:55 SWAMS or 01:18:57 SWAMS). For this reason, events 2-8-9 cannot be correct at the same time (i.e. are mutually exclusive), as events 5-6-12-13, 14-15, and 7-11-12-13 (connected by dashed lines in Fig. 9).


SWAMS-3 - March 8, 2014
Frequency (Hz)
60
40
20
0
00:00
00:05
00:10
00:15
00:20
00:25
00:30
00:35
00:40
00:45
00:50
00:55
01:00
01:05
01:10
01:15
01:20
01:25
01:30
01:35
01:40
01:45
01:50
01:55
02:00
100
90
80
70
dB re 1 uPa^2/Hz
[hann(256,periodic),overlap=80%,ftlen=256,srate=240]


SSEIR - March 8, 2014
dB re 1 uPa²/Hz
100
90
80
70
Frequency (Hz)
60
40
20
0
00:00
00:05
00:10
00:15
00:20
00:25
00:30
00:35
00:40
00:45
00:50
00:55
01:00
01:05
01:10
01:15
01:20
01:25
01:30
01:35
01:40
01:45
01:50
[hann(256,periodic),overlap=80%,ftlen=256,srate=240]


H01W-2 - March 8, 2014
Frequency (Hz)
60
40
20
0
00:00
00:05
00:10
00:15
00:20
00:25
00:30
00:35
00:40
00:45
00:50
00:55
01:00
01:05
01:10
01:15
01:20
01:25
01:30
01:35
01:40
01:45
01:50
01:55
02:00
100
90
80
70
dB re 1 uPa^2/Hz
[hann(256,periodic),overlap=80%,ftlen=256,srate=250]